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MEMORANDUM

Subject: Progress Report
ULI: FY12 Q3 Progress Report (4/1/2012–6/30/2012)

This document provides a progress report on the project "Advanced Digital Signal Processing" covering the period of 4/1/2012–6/30/2012.

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Revolutionary Research . . . Relevant Results

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Advanced Digital Signal Processing for Hybrid Lidar

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Presented to:
Annual ULI program review attendees

June 6, 2012

Presented by:
Mr. Paul Perez
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Outline

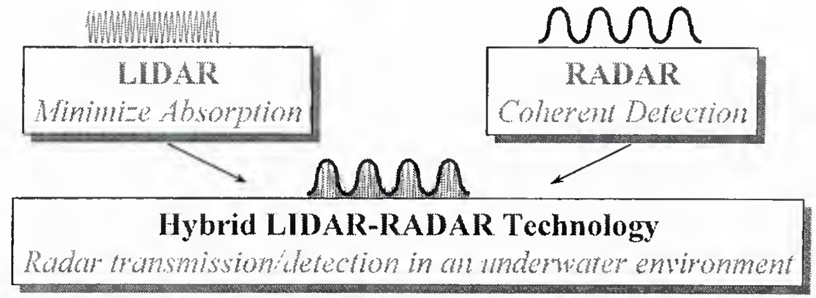
- Background and Objectives
- Approach and Challenges
- Light Propagation in Water
- Progress
  - Underwater laser range finder
  - A New Backscatter Reduction Approach
- Summary

Background and Objectives

Background

The Navy uses hybrid lidar-radar for underwater detection, ranging, communications, and imaging.

- Modulate the lidar laser light intensity with radar waveforms
- Recover the radar waveform from the received lidar optical signal
- Use coherent detection and other radar techniques to process the signal.



Objectives

To enhance hybrid lidar-radar performance:

- Develop and evaluate various digital signal processing (DSP) algorithms that will enhance the Hybrid Lidar-Radar performance.
- Implement the algorithms via DSP hardware
  - dynamically reconfigured via software (accomplish multiple missions with a single sensor)
  - real-time processing
  - reduced loss/temperature sensitivity

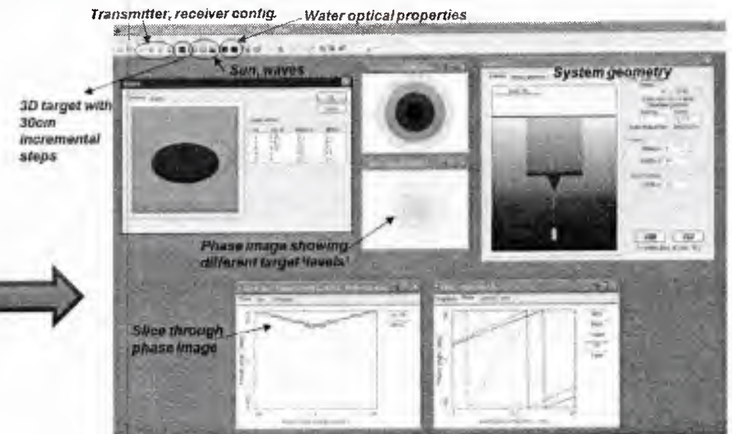
DSP Advantages

- **Component Availability/Cost**
- **Component Sensitivity/Performance**
- **Adaptability**
- **Real Time Processing**
- **Borrow waveforms/algorithms from RADAR.**

Approach and Challenges

Approach

- Leverage known radar processing techniques
- Use existing performance prediction models to generate data for multiple scenarios (system geometry/configuration, water optical properties, etc.)
- Use data to test the performance of DSP algorithms
- Compare results with experimental data
- Use COTS DSP, FPGAs, and Software Defined Radio (SDR) hardware to accelerate development and minimize cost

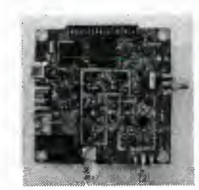


Rangefinder – used to generate hybrid lidar-radar signals for DSP algorithm verification

Principle Problems/Challenges

- Many COTS DSP hardware platforms are suitable for communications but lack performance for detection and ranging
- Radar propagation channel and the lidar propagation channel are very different

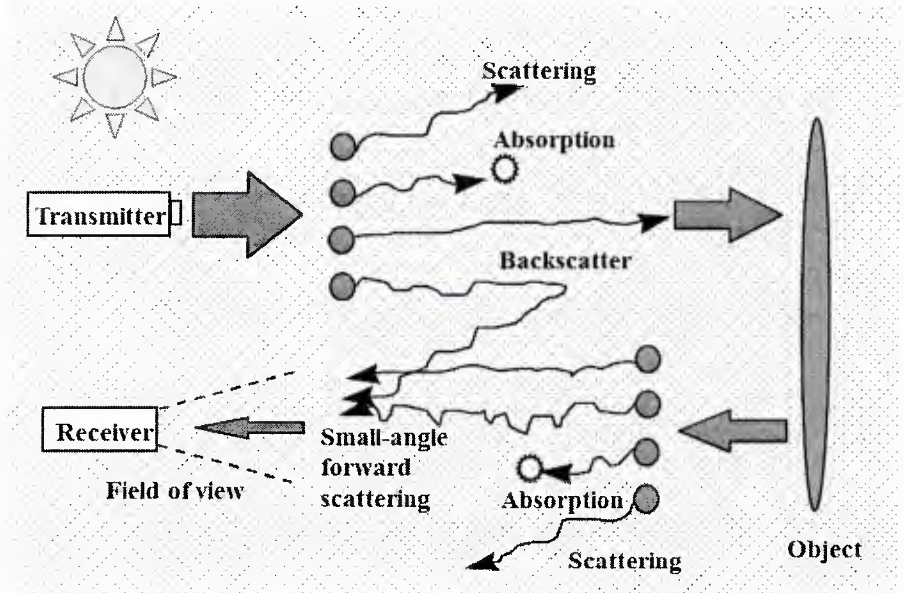
vs.

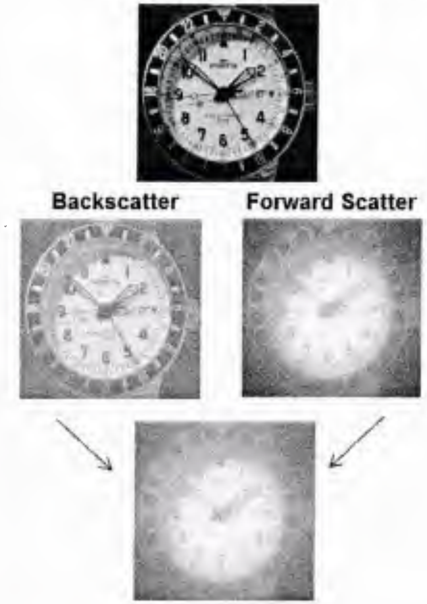


COTS Software Defined Radio

Evaluating performance of two COTS Software Defined Radios (Signal hound vs. COMBLOCK).

Light propagation in water

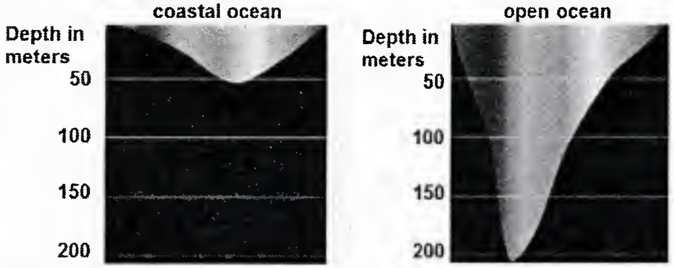




Wavelength Selection

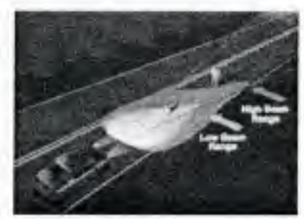
Light penetration – coastal ocean

Light penetration – open ocean



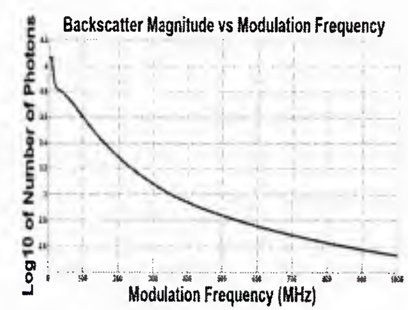
Absorption vs. Scattering Limited Performance

Scatter-limited detection – more light, more 'clutter'



Absorption-limited detection – more light, more range

Modulation Frequency



- **Absorption decreases total signal level at the receiver**
- **Scattering degrades image contrast, resolution, and reduces range accuracy**

Progress and Activity

Project Start: June 1st 2011

Summer 2011 & Fall 2011 (laser rangefinder)

- Participated in the ONR NREIP program at NAWCAD
- Assisted with water tank experiments
  - Resulted in SPIE publication/poster presentation
  - "Underwater Laser Rangefinder," Proceedings of SPIE, Ocean Sensing and Monitoring, Volume 8372
- Characterized Software Defined Radios

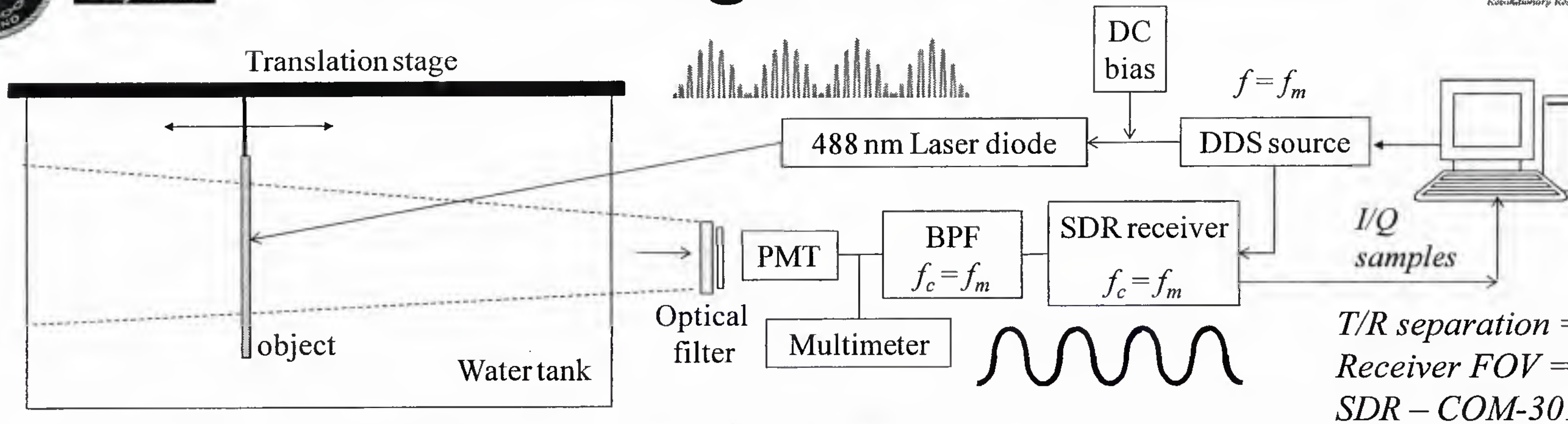
Spring 2012 (backscatter reduction)

- Became familiar with Navy Rangefinder simulation tool
- Identified new backscatter reduction technique
- Preliminary validation of backscatter reduction technique using simulation data from Rangefinder

Summer 2012 (planned)

- Participate in the ONR NREIP program at NAWCAD
- Thorough evaluation of backscatter reduction technique
- Validate backscatter reduction technique with laboratory experiments

Laser Rangefinder Results

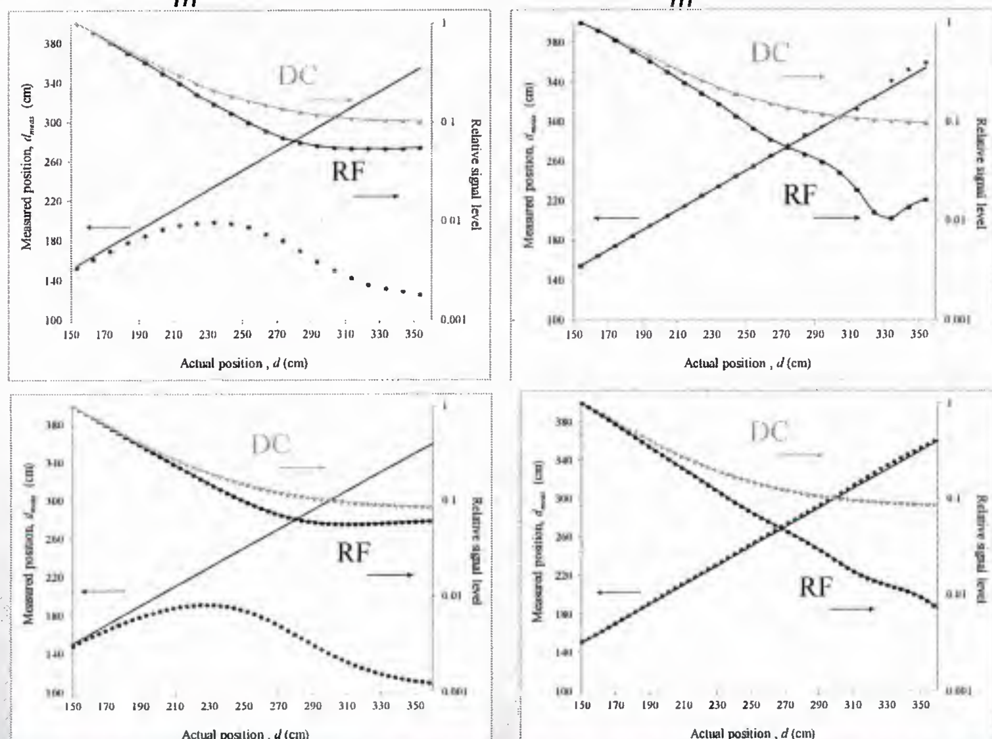


T/R separation = 12.5cm
Receiver FOV = 4 deg
SDR – COM-3011

f_m=20MHz | f_m=180MHz

Experiment

Simulation

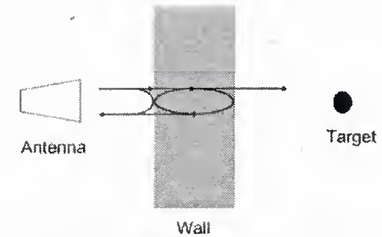


- Data shown presented in SPIE paper:
  "Underwater Laser Rangefinder," Proceedings of SPIE, Ocean Sensing and Monitoring, Volume 8372
- Experimental results show only the mean values to compare with model predictions
- Range error as a function of integration time is reported in the paper

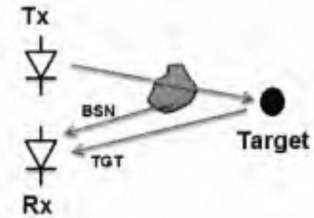
c= 1.6 m^{-1}

A New Backscatter Reduction Approach

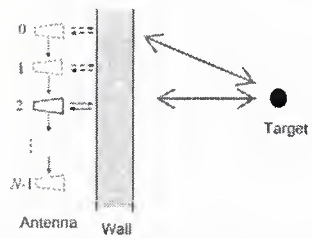
Leverage Techniques Developed for Through the Wall Imaging (TTWI) Radar



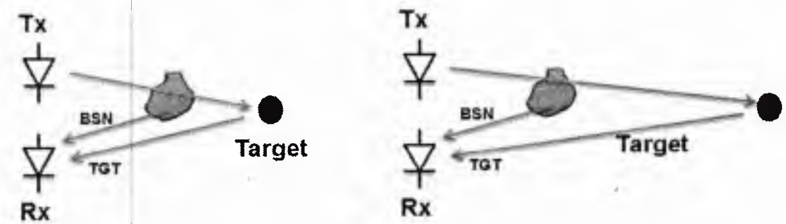
TTWI – unwanted returns from the wall



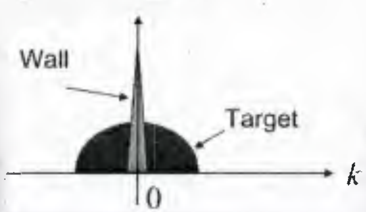
Hybrid Lidar – unwanted returns from backscatter (BSN)



Wall return is independent of antenna position
Target return phase varies with antenna position

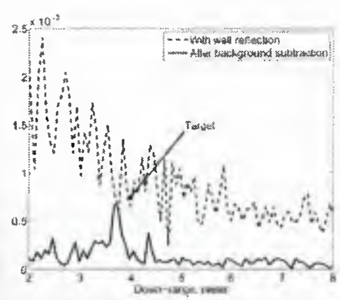


Backscatter is independent of receiver position
Target return phase varies with receiver position

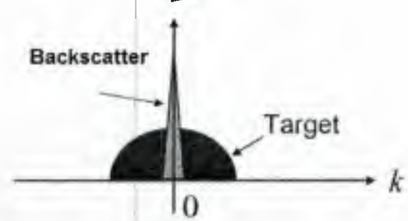


Spatial frequency domain

Spatial frequency filter



Enhanced performance



Spatial frequency domain

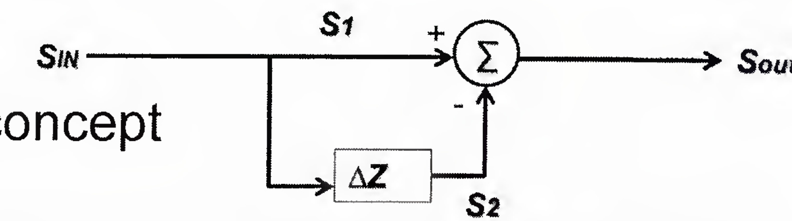
Spatial frequency filter

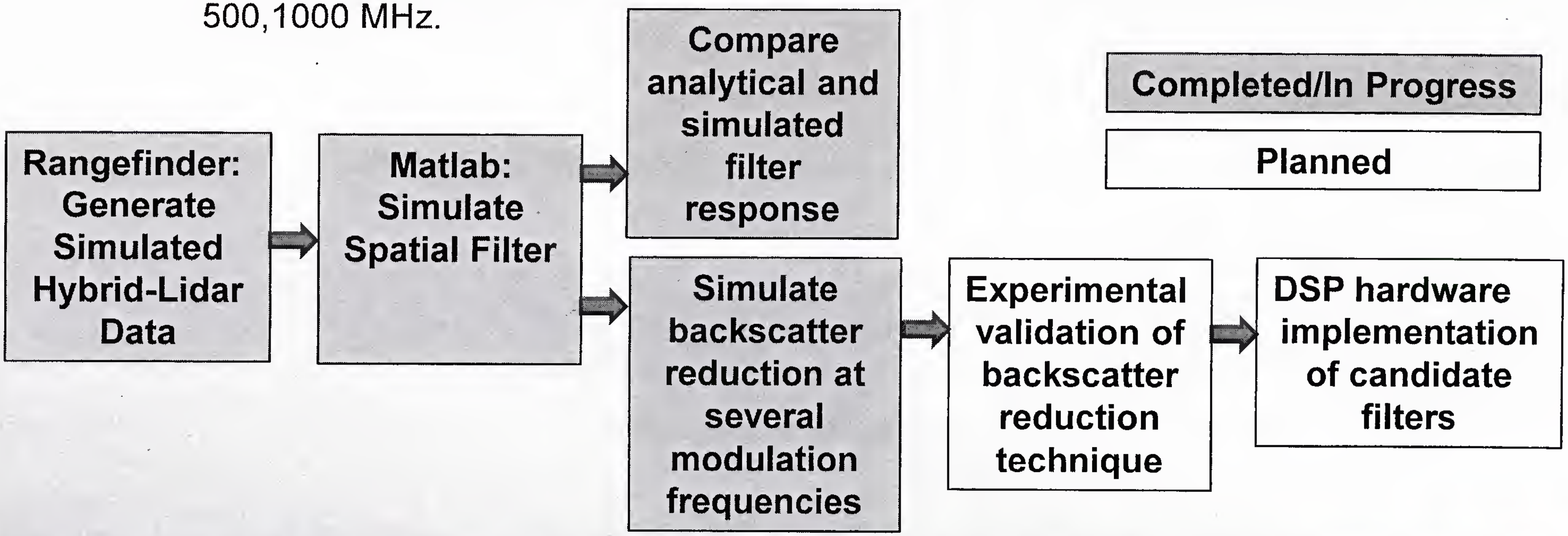
?

Enhanced performance

Spatial Frequency Filters

- There are a variety of spatial filters that have been developed for radar
  - Single delay line, multiple delay lines
  - Recursive, feed forward
  - etc.
- Selected single delay line for proof-of-concept
  - Simple and easy to implement
  - Derived the filter response as a function of delay and water attenuation coefficient
  - Investigated backscatter reduction in high turbidity conditions($2.4 m^{-1}$) at 100, 500,1000 MHz.



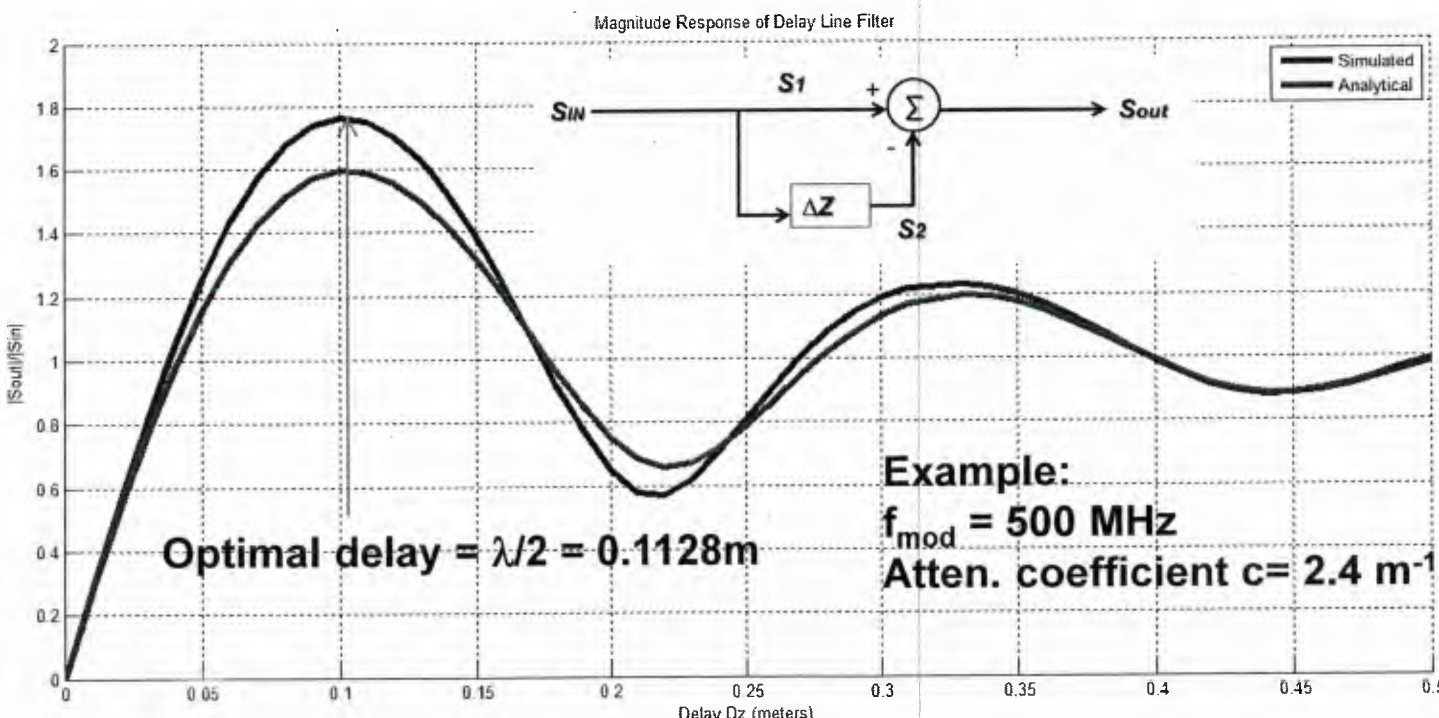


Delay Line Filter Transfer Function

Derived delay line filter response:

$$|G(c,\Delta z)| = \sqrt{1 + e^{-2c\Delta z} - 2e^{-2c\Delta z}cos(k\Delta z)}$$

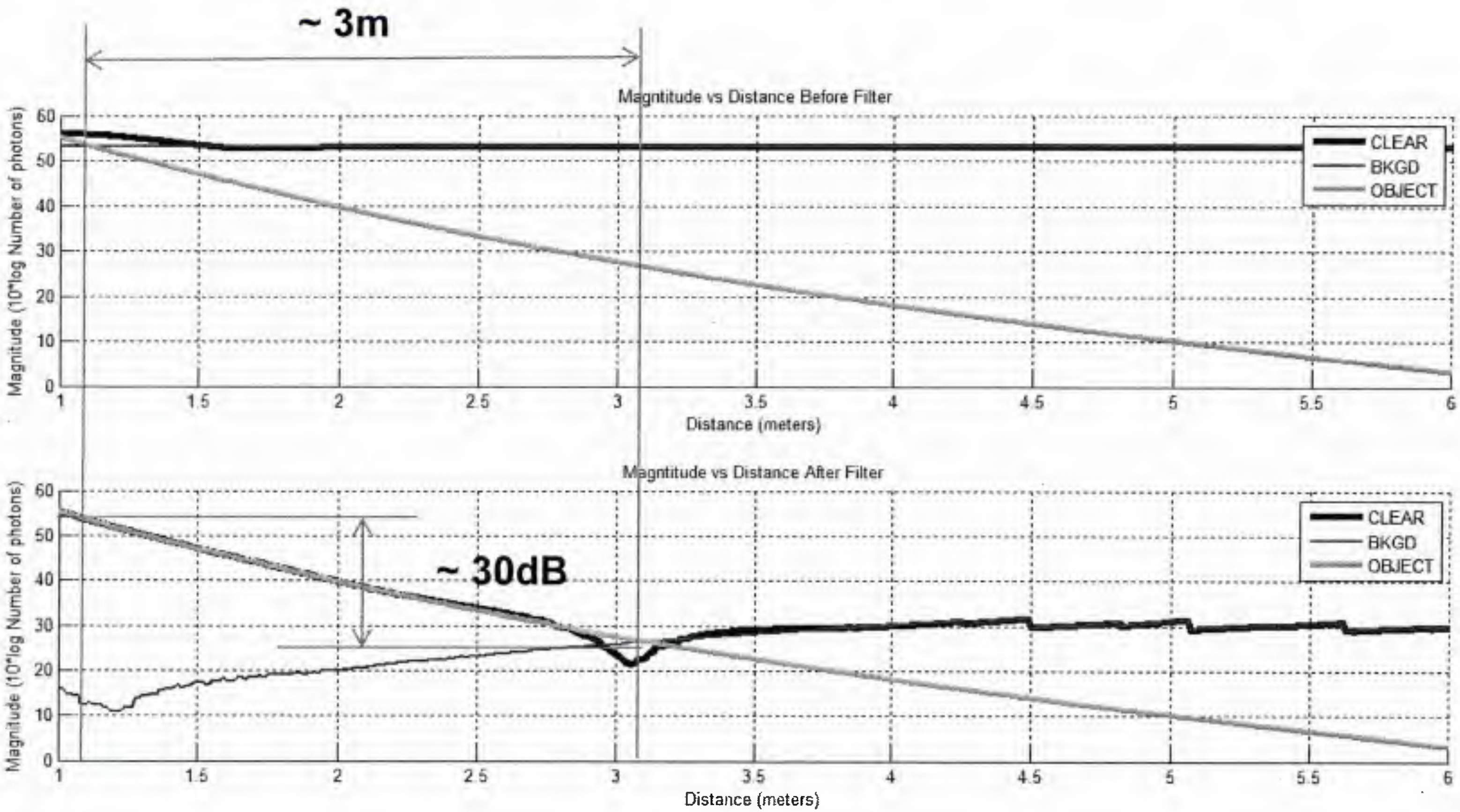
- Good agreement between analytical and simulated response



Backscatter Reduction Simulation

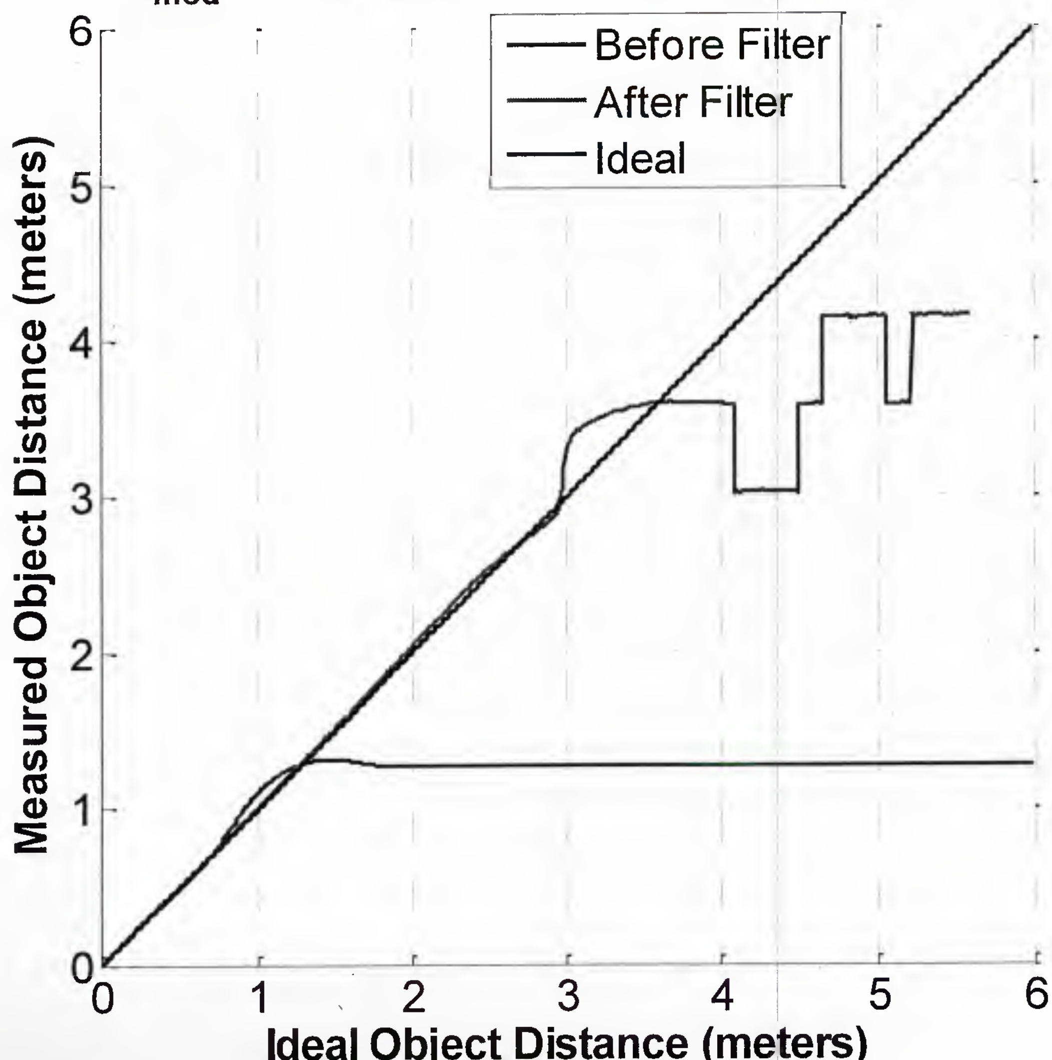
f_{mod} = 100 MHz; Δz = 1.13m; c = 2.4m^{-1}

~30dB backscatter reduction; ~3m improvement in range;



Range Performance

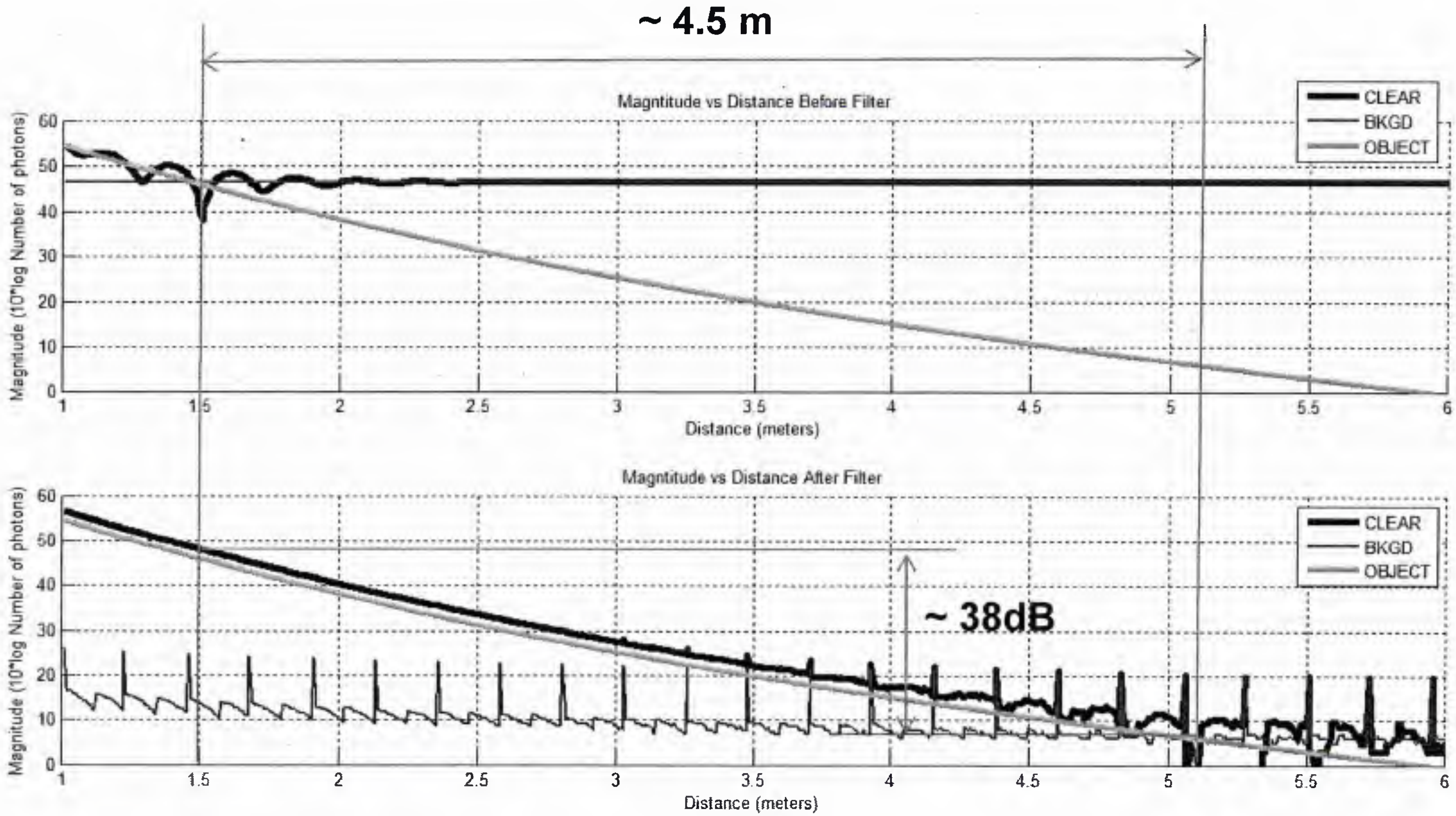
f_{mod} = 100 MHz; Δz = 1.13m; c = 2.4m^{-1}



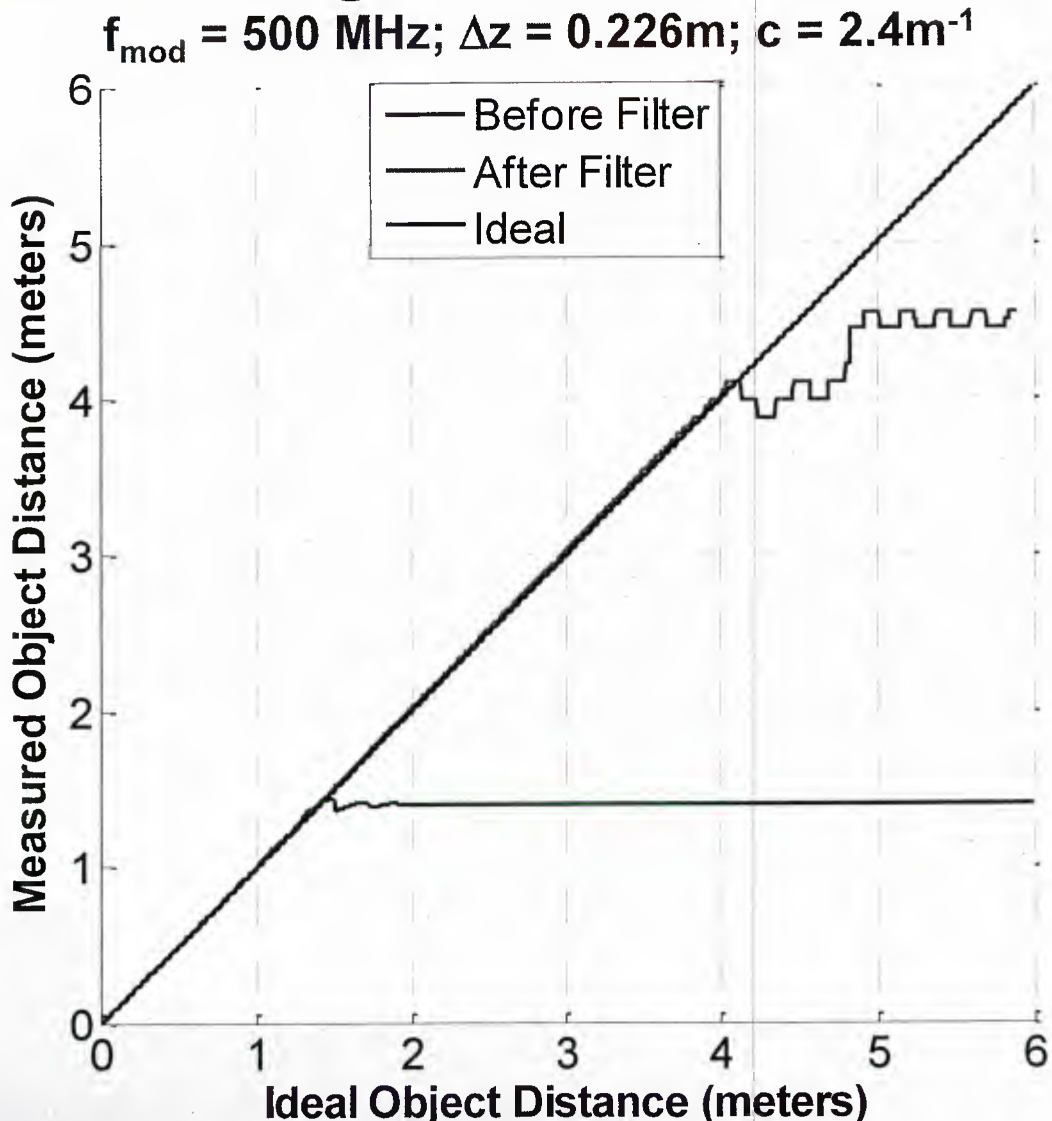
Backscatter Reduction Simulation

f_{mod} = 500 MHz; Δz = 0.226m; c = 2.4m^{-1}

~38 dB backscatter reduction; ~4.5 m improvement in range;



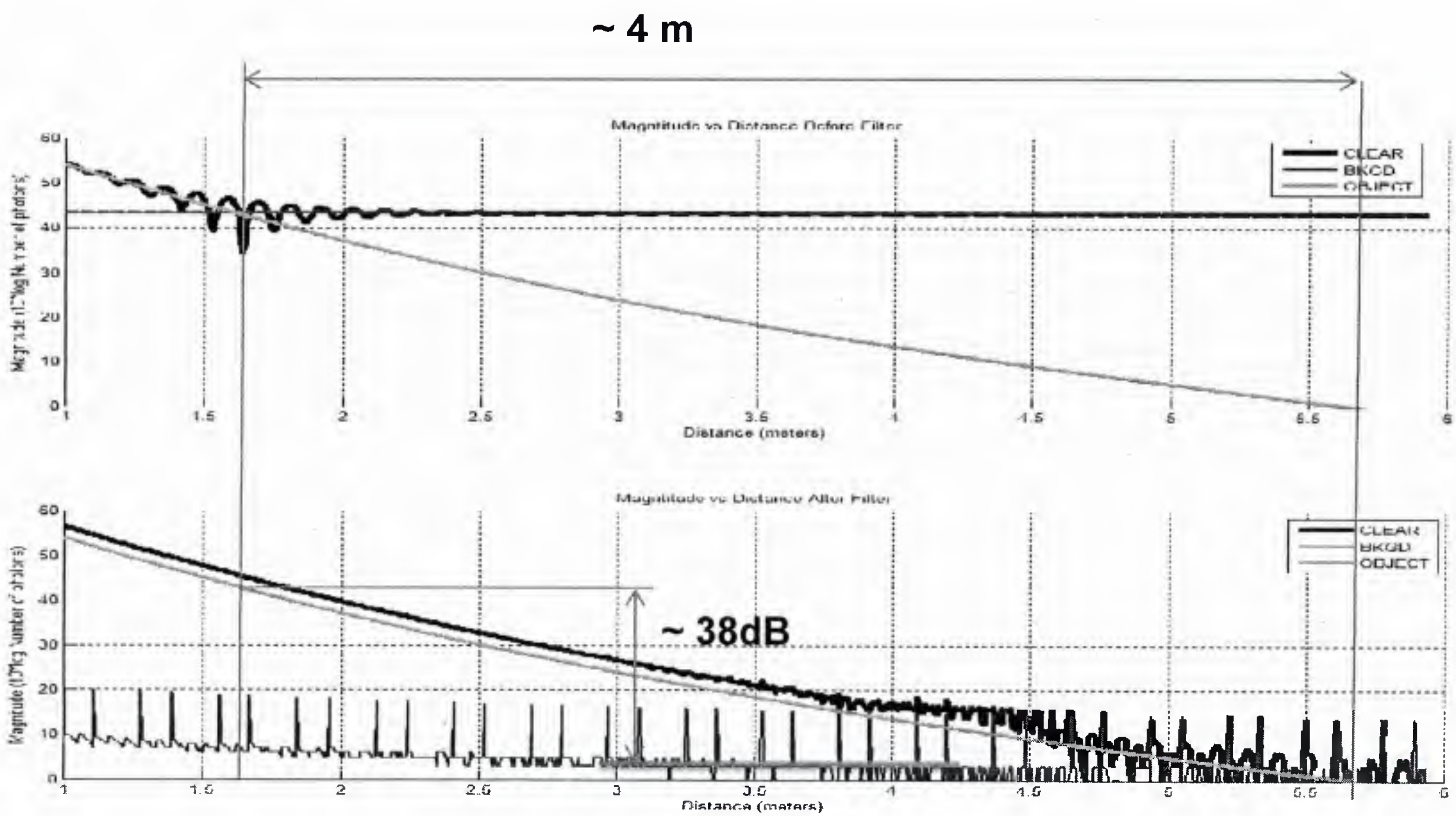
Range Performance



Backscatter Reduction Simulation

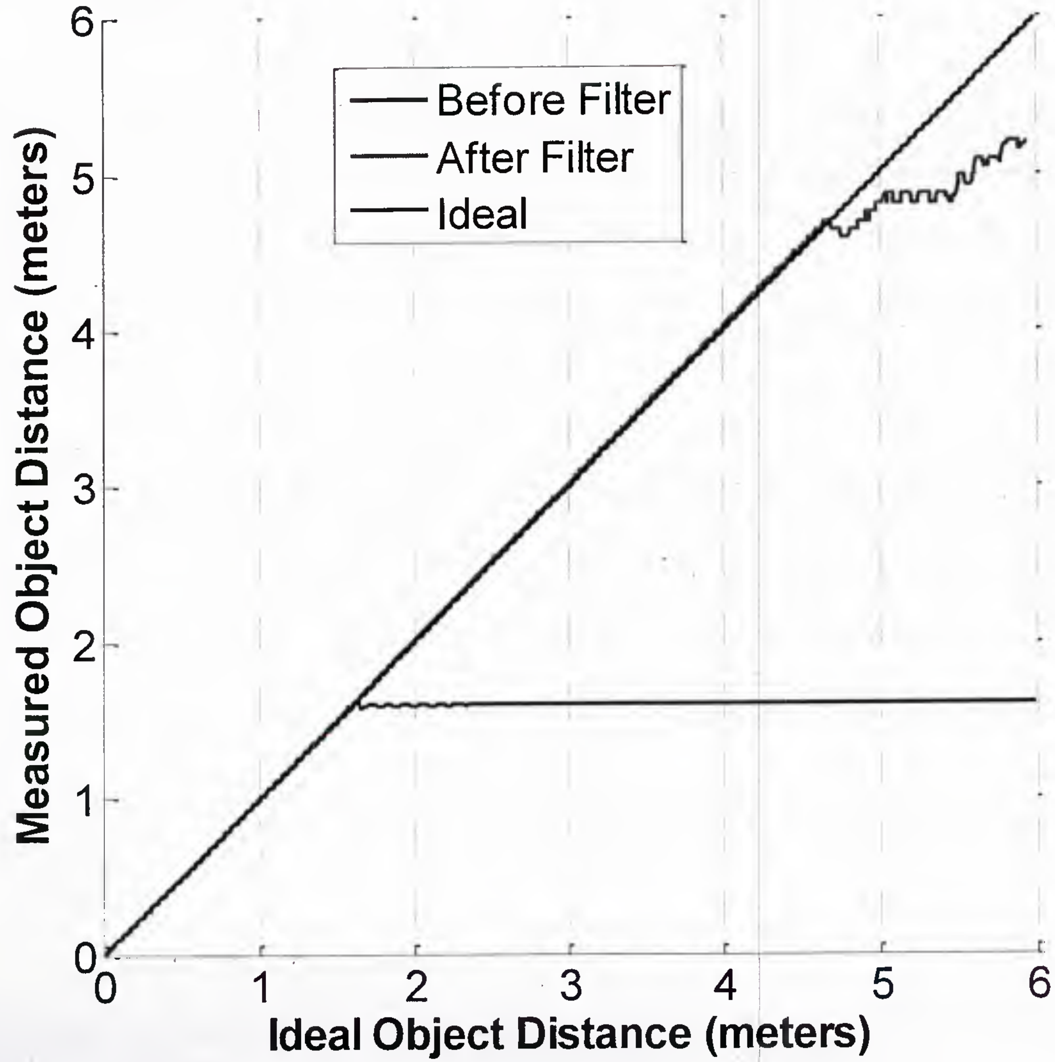
f_{mod} = 1000 MHz; Δz = 0.113m; c = 2.4m^{-1}

~38dB backscatter reduction; ~4 m improvement in range;



Range Performance

f_{mod} = 1000 MHz; Δz = 0.113m; c = 2.4m^{-1}



Summary

- Experience gained in summer 2011 internship at NAWCAD:
  - Gained background in underwater optics
  - Learned basics of RF modulation/demodulation via digital components
  - Performed initial experiments that led to SPIE publication/poster presentation
- Accomplishments during 2011-2012 academic year:
  - Courses taken/knowledge gained: Signal Processing
  - Characterized a commercial SDR and concluded that it is convenient to interface with an SDR to obtain the needed data for ranging calculations.
  - Became familiar with Rangefinder simulation tool
  - Identified a new backscatter reduction technique that will improve range calculations.
- Future plans:
  - 2012 Summer internship at NAWCAD – experimental validation of delay line predictions
  - Participate in the student poster competition at the 2012 MTS/IEEE Oceans Conference (October, 2012)
  - Courses planned: Signal Processing, Software Defined Radio